
Recovering Audio Sources in a multi-path Environment

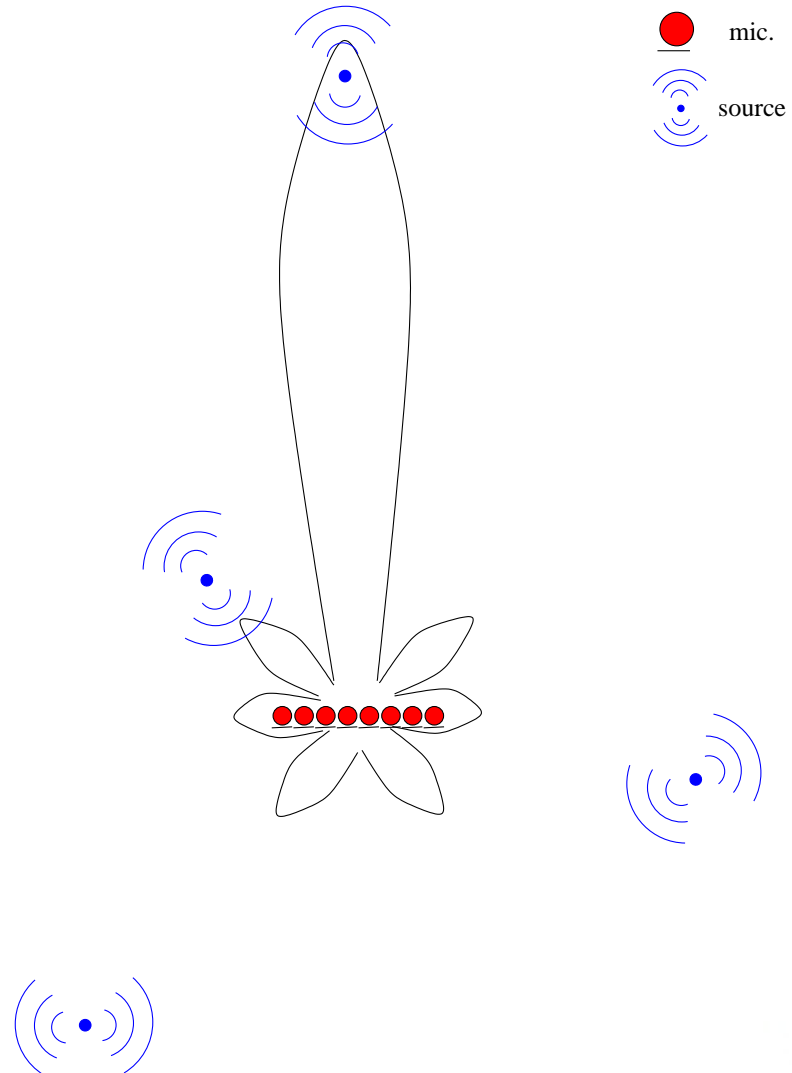
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Air-coupled Acoustic Sensors Workshop

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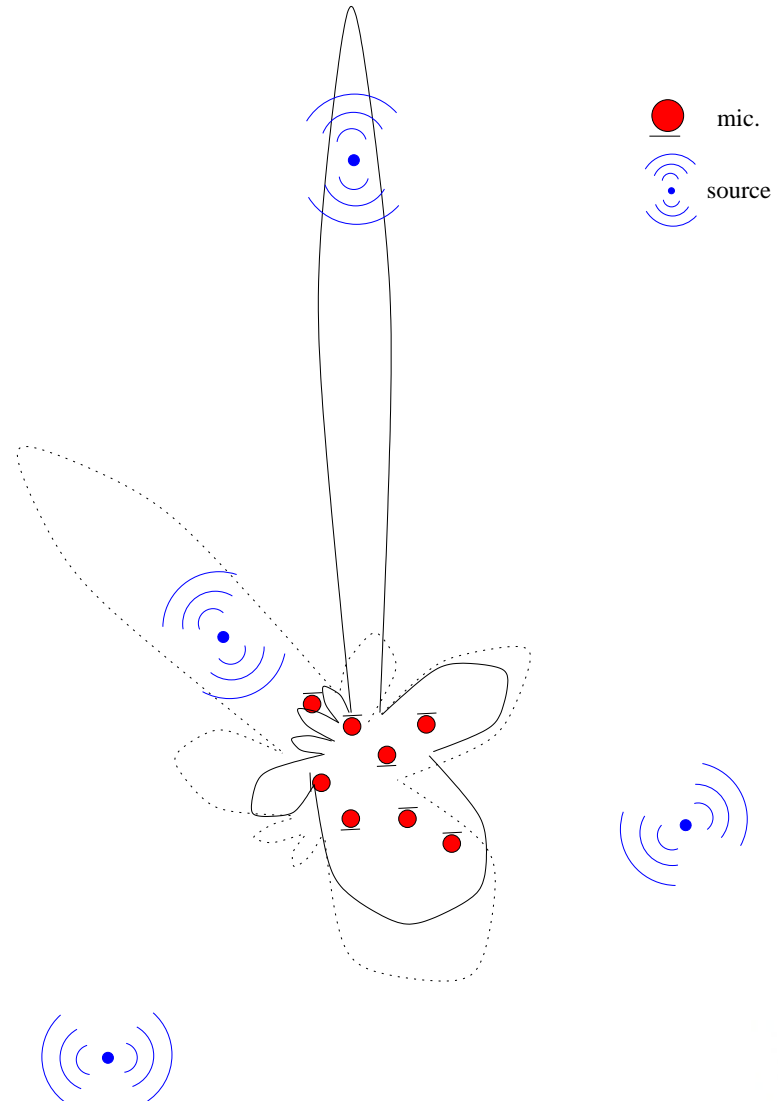
Geometric (Adaptive) Beamforming

- What it is
 - microphone array with fixed geometric configuration
 - adaptive algorithms to steer and adjust beam pattern
- Typical Applications
 - Attenuation of jammers
 - source localization
- Problems/Issues
 - Requires know/fixed array configuration
 - Cannot handle multiple sources
 - Signal leakage, reverberation



Statistical (Blind) Beamforming

- What it is
 - Multiple sensors at arbitrary locations
 - adaptive algorithm to recover independent/decorrelated source signals
- Typical Applications
 - simultaneous recovery of multiple sources
 - jammer attenuation under reverberation, and target signal leakage
- Problems/Issues
 - requires low noise sensors
 - computational complexity



Recovering Speech from Simultaneous Recording (Statistical Beamforming Demo)

... isolating individual speakers with multiple microphones ...

- Instantaneous mixture - corresponds to environment with no reverberation and known time delays.
- Solution can't assume knowledge of speaker/source location - requires a “blind” algorithm.
- Demo 1 - linear mixing of 10 speakers.
- Demo 2 - “real-world” deconvolution with 2 speakers.
- Sarnoff algorithm exploits non-stationarity of speech signal, performing multiple decorrelation across time to compute a matrix of “unmixing” FIR filters.

The Problem: Convolutional Mixture



Acoustic signals $x(t)$ recorded simultaneously in a reverberant environment $A(\tau)$ can be described as sums of differently convolved sources $s(t)$.

$$x(t) = \sum_{\tau=0}^P A(\tau) s(t-\tau) + n(t)$$

with $\dim(x) \geq \dim(s)$

Context on Blind Source Separation

PCA:

$$\mathbf{x} = \mathbf{R}\mathbf{s}$$

$$\mathbf{R} : \mathbf{s} = \mathbf{R}^T \mathbf{x}$$

$$\langle s_i s_j \rangle = \delta_{ij} \lambda_i$$

ICA:

$$\mathbf{x} = \mathbf{A}\mathbf{s}$$

$$\mathbf{A} : \mathbf{s} = \mathbf{A}^{-1} \mathbf{x}$$

$$\mathbf{W} : \mathbf{s} = \mathbf{W} \mathbf{x}$$

$$\langle s_i^n s_j^m \rangle = \delta_{ij} \lambda_i^{n+m}$$

$$\langle s_i(0) s_j(t) \rangle = \delta_{ij} \lambda_i(t)$$

BSS:

$$\mathbf{x} = \mathbf{A} \otimes \mathbf{s}(t)$$

$$\mathbf{A} : \mathbf{s}(t) = \mathbf{A}^{-1} \otimes \mathbf{x}(t)$$

$$\mathbf{W} : \mathbf{s}(t) = \mathbf{W} \otimes \mathbf{x}(t)$$

$$\langle s_i^n(0) s_j^m(t) \rangle = \delta_{ij} \lambda_{inm}(t)$$

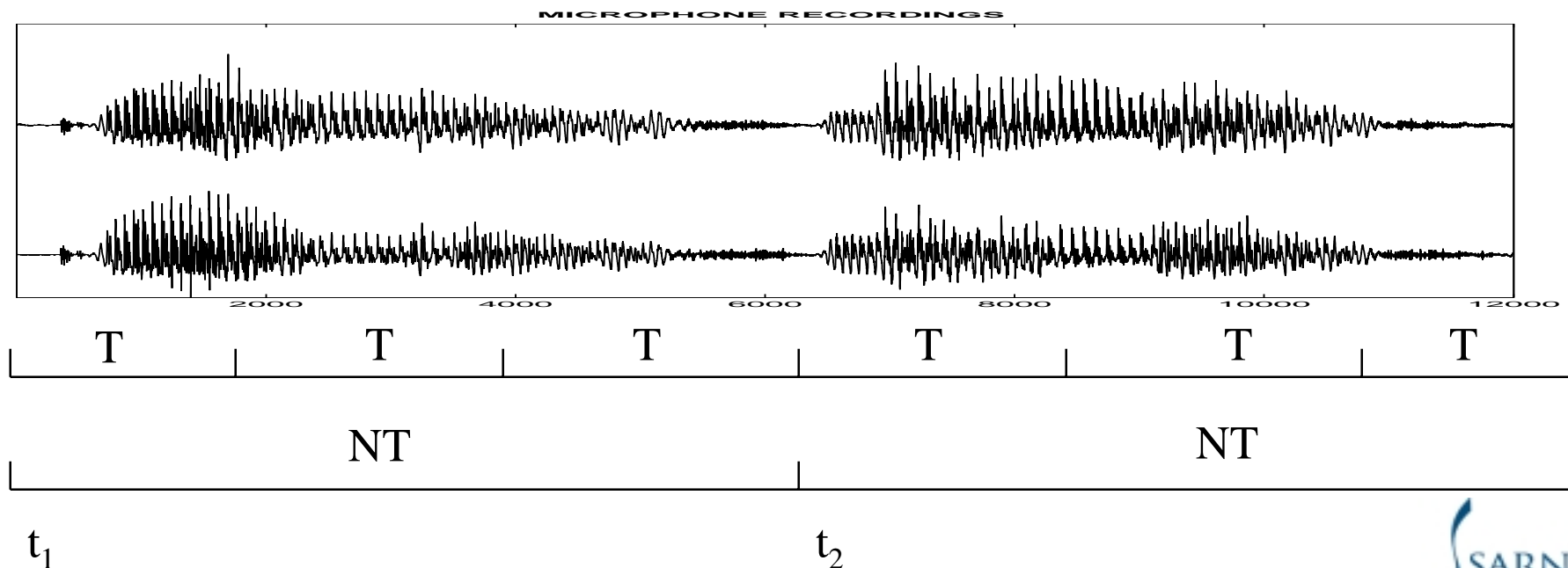
$$\langle s_i(t) s_j(t') \rangle = \delta_{ij} \lambda_i(t, t')$$

Approach - Use Non-stationarity

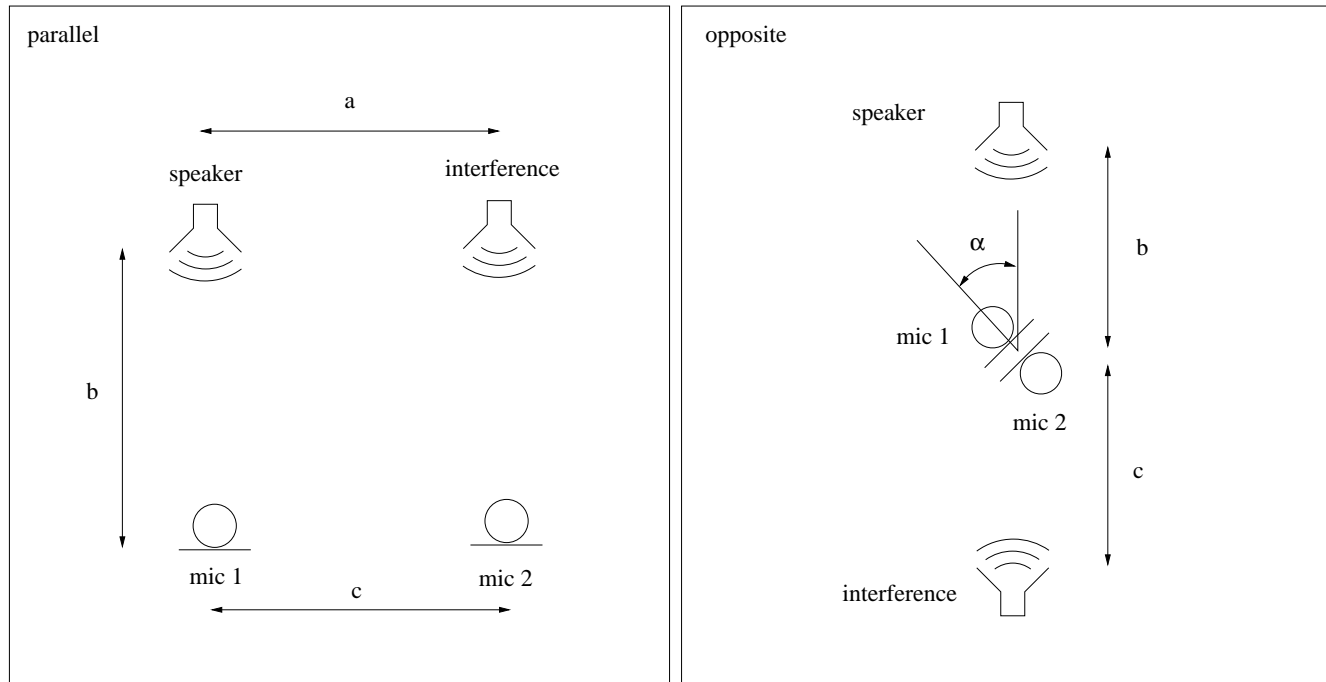
Measure time dependent second order statistic

$$\bar{\mathbf{R}}_{\div}(\omega, t) = \frac{1}{N} \sum_{n=0}^{N-1} \mathbf{x}(\omega, t + nT) \mathbf{x}^H(\omega, t + nT)$$

Where $\mathbf{x}(\omega, t)$ are the frequency components of frame $[\mathbf{x}(t), \dots, \mathbf{x}(t + T)]$



Experimental Setup: Speaker with Interfering Source



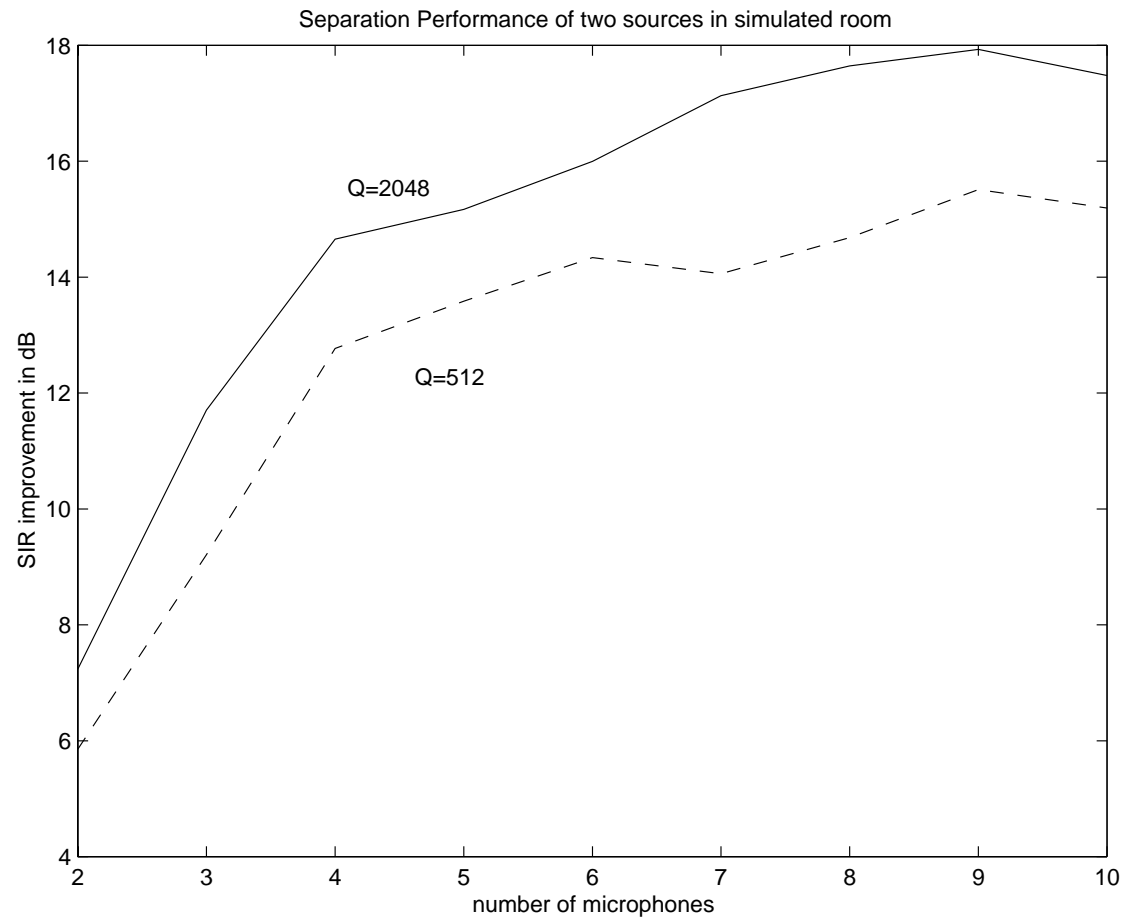
Reverberant environment (small office room). The interfering signal was a competing speaker or music.

Left: $a = b = 50?$, $c = 50?$, $6?$.

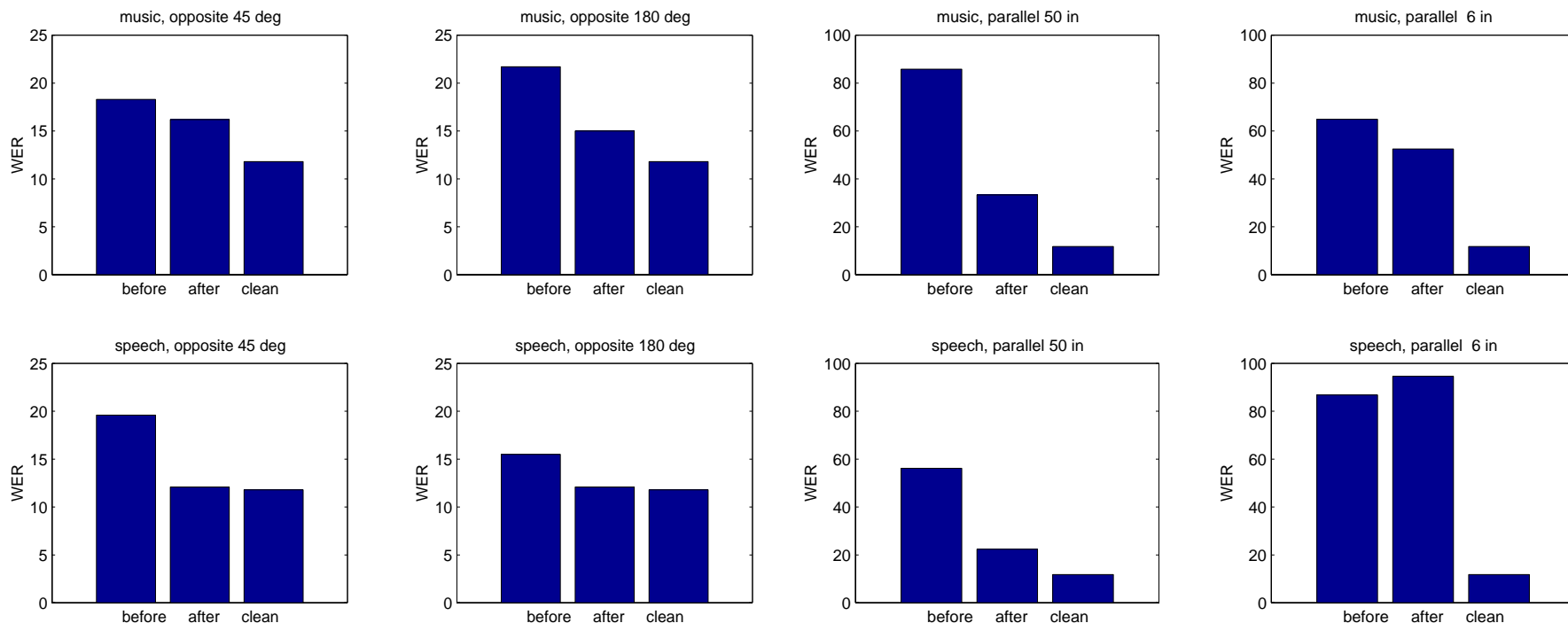
Right: $b = 30?$, $c = 60?$, $\alpha = 45^\circ$, 180° .

Multiple Microphone Performance

Performance of multiple microphones in simulated room (small office) for separating a speaker from music background. Microphone distance 2m.



Speech Recognition Improvement



Word error rate (WER) of ViaVoice (IBM) on a short text (Wallstreet Journal article of 760 words length) before and after source separation. The result is contrasted to clean recording with no interfering source.

up to **50% reduction in word error rate**
for IBM Viavoice